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A Qualitative and Quantitative Structural Landscape Analysis

Case Study in Monteverde, Costa Rica

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Dedicated to my family
whose love and support
carry me.

Abstract

Forest fragmentation translates a geographical isolation process and has been shown to influence the abundance, the movements and persistence of many species. The structure of the highly fragmented forests of Monteverde, Costa Rica, may exercise a relevant influence on the species richness and individual abundance of many forest-dwelling understory bird species.

This study compares the landscape structure composition and configuration of 14 circular areas of 12.5 ha each, surrounding bird sampling site. Two subsets of 7 study sites are each located in the continuous and in the fragmented habitat respectively. The landscape pattern analysis has been performed on two landscape models. First one refers to an image classification by multiresolution segmentation (image treatment approach), whereas the latter one is based on an in-field classification (field approach). The aim of the structural landscape analysis is to examine the implications of scale on the two models, the pertinence of the landscape structural metrics and to qualify and quantify the study areas around the 14 bird observation sites.

The results have shown scale dependency of all the five chosen metrics. Furthermore scale is an important parameter in both approaches and influences the landscape models in the form of lower and upper limits of scale, and observation scale. Therefore, a judicious choice of scale is crucial.

The results of four of the five chosen metrics were useful in the habitat characterization, whereas the results of one metric did not allow any description of the landscape.

The field approach provides a high level of thematic detail, but is very time consuming. The image treatment approach is the faster method and applicable on big study areas. Its structural detail may be better than the one of the field approach, but the spectral information of the image allows the identification of only a restricted number of thematic classes. The choice between the two approaches has to be made on the basis of the ecology of the target species. The level of thematic detail of the image treatment approach may not be sufficient when the target species show a high sensitivity towards vegetation changes.

Resumen

La fragmentación del bosque genera procesos de aislamiento geográfico y ha sido demostrado que influye sobre la abundancia, el movimiento y la persistencia de muchas especies. En la región de Monteverde, Costa Rica, la estructura de los bosques fuertemente fragmentados podría ejercer una influencia relevante sobre la riqueza y la abundancia de muchas especies de aves de bosque.

Este estudio compara la composición y la configuración del paisaje de 14 áreas circulares de 12 ha cada una, alrededor de sitios de muestreo de aves. Dos grupos de 7 zonas de estudio cada uno, están localizados en un hábitat continuo y fragmentado respectivamente. Un análisis de la estructura del paisaje ha sido realizado sobre dos modelos de paisaje. El primero se refiere a la clasificación de una imagen aérea por segmentación multiresolucional (enfoque *análisis de la imagen*) mientras el segundo se refiere a una clasificación realizada directamente de observaciones de campo (enfoque *de campo*). La meta de la análisis estructural del paisaje es de examinar las implicaciones de la escala sobre los dos modelos, la pertinencia de los índices estructural del paisaje y de calificar y cuantificar las áreas de estudio alrededor de los 14 sitios de muestreo.

Los resultados han mostrado dependencia de la escala en los cinco índices escogidos. Además, la escala es un parámetro importante en cada uno de los enfoques e influye los

modelos del paisaje en tres formas diferentes: escala menor, mayor y de observación. Así, la selección acertada de la escala es un criterio muy importante.

Los resultados de cuatro de los cinco índices fueron útiles para la caracterización del hábitat, mientras que los resultados de un índice no permitió una descripción del paisaje.

El enfoque *de campo* genera un alto nivel de detalle temático pero consume mucho tiempo. El enfoque *análisis de la imagen* es un método más rápido y es aplicable en grandes áreas de estudio. Aquí, el detalle estructural puede ser mejor que en el enfoque *de campo,* pero la información espectral de la imagen permite, sin embargo, la identificación de solo un número limitado de clases temáticas. La selección entre los dos enfoques debe ser hecha sobre la base de la ecología de las especies seleccionadas. El nivel de detalle temático del enfoque *análisis de la imagen* puede ser insuficiente cuando las especies seleccionadas muestran una alta sensibilidad a los cambios de vegetación.

ACKNOWLEDGMENTS

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1 INTRODUCTION

1.1 GENERAL FRAMEWORK

In the last decades, large areas of our planet have been subject to a very intense anthropic influence in terms of landscape transformation. Forest fragmentation[1] is one of the most important changes that an increasing number of areas worldwide had to face in the past. Forest fragmentation resulting in forest patches translates a geographical isolation process and can therefore influences the population dynamics.

In order to evaluate the influence of the fragmented forest on animal populations, MacArthur and Wilson proposed the Theory of Island Biogeography[2]. It states that more species are sustained in large habitats that are close together or connected, and are shaped in a way that there is more interior area and less edge (Wu and Vankat 1995). The theory has long been widely used in both theoretical and practical conservation biology (Freemark *et al.* 1995), to predict quantitatively the number of species likely be found in a given area. But the limits of this theory are important: the theory does not consider the influences of edge effects and the surrounding matrix which are both greatly important factors in the determination of habitat quality for certain forest dwelling species (Bankroft *et al.* 1995). Research on ovenbirds abundance has shown that surrounding forest cover explained more variation than patch size did (Lee *et al.* 2002).

The smaller the patches the more the physical properties of the surrounding system become important. Temperature and humidity of the edge of the patch can be very different from the interior of the system. The altered microclimate of the edge has been found unsuitable for some species, while promoting an increase in the abundance of others (Turner 1996). In addition, a high shape complexity increases the vulnerability of the patches to external disturbances, for instance windstorms or droughts, with consequences for the survival of these patches and of the supporting biodiversity (Nilsson and Grelsson 1995).

Animal perception of the degree of isolation of fragmented forest is species-dependent (Farina 1998). Small species may perceive the system as continuous, whereas bigger animals suffer from the consequences of a serious habitat fragmentation. The distance between the patches can have an inhibiting influence on the daily or seasonal migration processes of these animals. As a result, the fragmented forest presents a different habitat quality than the continuous forest and can be an inapt habitat for certain species which results in a general loss of biodiversity.

Ecological corridors normally work as linking elements between the patches and facilitates the movement of species between them. Hence, they can increase the survival and the genetic viability of a species, especially where the distance between patches does not ease daily and seasonal migratory movements.

Bird species of tropical forests react more sensitive on fragmentation than bird species of the boreal forests. Whereas boreal bird species travel long distances to colonize

1 The fragmentation process is characterized by a decrease in the total habitat area and the division of the habitat surface in smaller fragments called patches (Burel & Baudry 1999)

2 The theory states that the species diversity of an island is primarily determined by two processes: immigration and extinction. The theory can be applied on both sea and land islands.

forest patches, for tropical birds even short distances between the patches constitute real barriers to their movement. Especially birds breeding in the forest interior and wintering in the tropics are affected by fragmentation of their habitat (Blake and Karr 1987). Furthermore, bird species living in isolated forest patches are generally more often subject to predation than in continuous forest patches (Wilcove 1985). Clearing of understory may also be a negative factor, because many species breed in the shrub layer or find resources at this forest level (Willson *et al*. 1994).

Generally speaking, at a certain level, forest fragmentation leads to a decrease in species and individual abundance. But at an early stage, forest fragmentation creates new types of habitats for species for which the continuous habitat is not apt[3]. Ecosystem management is all about finding these thresholds assuring a maximum species diversity.

Birds belong to the best studied groups of organisms in the tropical forest and since they play an integral role in the tropical ecosystem, they provide an excellent opportunity to understand faunal responses to habitat fragmentation. A sustainable management of the increasingly fragmented forest demands the identification of the sensitive and vulnerable bird species (consult Bierregaard and Stouffer 1997) and the consideration of their biological and ecological characteristics.

The scientific discipline of landscape ecology originates in the consciousness of the need to link the spatial dimensions of geography with the time-scale concerns of ecology. One of the first principles of landscape ecology claims that landscape structures strongly influence the ecological processes. According to Forman and Godron (1986), landscape ecology is the study of *structure*, *function*, and *change* in a heterogeneous land area which contains interacting ecosystems. Structure refers to the spatial relationships between the distinctive ecosystems, function refers to the interactions between the spatial elements and change refers to the alteration in the structure and function of the ecological mosaic through time. Since human demographic growth has become the major source of disturbances in ecological systems, landscape ecology involves other scientific disciplines such as sociology, psychology and economics.

The size of a landscape is determined by the purposes and needs for which the principles of landscape ecology are being used. The spatial extensions of landscapes used for wildlife management studies are determined by the target animal's perception of the environment and are normally chosen to enclose the habitat extension of an individual. Because every organism scales its environment differently, landscape sizes differ too.

This project concentrates on the dimension of the structural landscape analysis which is a statistical approach. The biological dimension of the problem constitutes the leitmotif of this analysis and determines the choice of parameters at all levels of the project. The qualitative and quantitative description of the landscape is performed on two models corresponding to two different landscape modeling approaches.

The aim of a structural landscape analysis is to qualify and quantify landscape pattern in order to find out more about the principles of landscape ecology (see Iorgulescu & Schlaepfer 2002). The structural analysis of the fragments examines their different attributes such as density, isolation/connectivity, size, shape, aggregation and boundary characteristics. The structural analysis is based on two main objectives: primary, the

3 Birds are able to detect slight changes in habitat features and seem to be attracted to tree-fall gaps (Blake and Hoppes 1986). Since in tree-fall gaps, resources are particularly abundant, they constitute a preferred feeding ground of birds.

analysis of the composition of the ecosystem, i.e. a description of the different ecosystems present in the landscape, and secondary, the analysis of the configuration of the landscape, i.e. an analysis of the landscape by using statistical methods and metrics.

Structural analysis call on methods of remote sensing and geographical information systems (Caloz and Collet 2001, Collet 1992, Eastman 1995).

The pattern detected in any ecological mosaic is a function of scale. Latter one encompasses both landscape extent and pixel size of the image, the upper and lower limits of scale (see Iorgulescu and Schlaepfer 2002). Hence, the assessment of the landscape structure can not go beyond the the spatial extension of the landscape, nor below the pixel size of the image.

1.2 SPECIFIC GOALS

The aim of this work is to answer the following points:

1. What are the implications of scale on the image treatment approach and the field approach respectively?
2. How pertinent are the chosen metrics?
3. Which is the landscape around the 14 bird observation sites?
4. Verify the following hypothesis[4]: The set of landscapes of the continuous habitat is characterized by at least 60% to 70% of primary forest cover and the set of landscapes of the fragmented habitat of approximately 30% to 40%.

1.3 PROJECT ORGANIZATION

Main supervisors:	Prof. Rodolphe Schlaepfer	(GECOS-EPFL)
	Régis Caloz	(LaSIG-EPFL)
Co-supervisor:	Dr. Philippe Heeb	(Zoology-UNIL)
With the scientific collaboration of José Edgardo Arévalo		(Zoology-UNIL)

1.4 PROJECT PLANNING

This project is divided in three main parts:

1. Conception and elaboration of landscape models using geographic information systems GIS. The software tools used in particular are: ERDAS imagine 8.5, ArcView 3.2, Idrisi 32 and Manifold. The GIS is based on aerial photos and topographic maps.

4 The choice of the location of the study sites has been made by José Edgardo Arévalo, based on this hypothesis.

2. In field verification of the classification by multiresolution segmentation (image analysis approach), and field classification and identification of the corresponding vegetation classes (field approach).
3. Structural landscape analysis of the 14 study areas. The aim of this analysis is the description of the landscape structure of the 14 sites and a comparison of the two landscape modeling approaches (image analysis vs. field) on the metric level.

In appendix 1, the reader will find the data analysis diagram.

2 STUDY SITES AND DATA SOURCES

2.1 STUDY DOMAIN

The study domain is located in Monteverde (10° 15’ N, 84° 46’ W), Costa Rica, between 1000 and 1500 m above sea level. The area is located within a life zone[5] which will be considered homogeneous, i.e. non existence of any ecological gradient. The study zone consists of two different degrees of forest fragmentation: the continuous habitat[6] which is linked to the Cloud Forest of Monteverde, and the fragmented habitat in form of isolated patches in the agricultural zone (appendix 2).

The study area is divided in 14 circular landscapes, 7 in each continuous and fragmented forest areas, each one of 200 meter radius. The central points of these landscapes correspond to the bird sampling sites.

The region of Sta. Elena and Monteverde is located a few kilometers from the Continental Divide of the Cordillera de Tilaràn, the mountain chain whose slopes lead towards the Atlantic in the East and towards the Pacific in the West. Hence, the weather in the area is conditioned by both these oceans. In the dry - but very windy - season during December-May, the Atlantic brings very humid air, whereas the air masses from the Pacific are dry and warm. The strong winds from the Atlantic whip the water pregnant air masses over the top of the continental divide. The uppermost parts of the Pacific slopes are then bathed in a cool mist, competing with the sun and the dry air dominating the weather on that side of the Cordillera de Tilaràn. During the rainy season from April to November, the winds get weaker, but still bring essential moisture to the area. These special climatic conditions gave birth to the evergreen Monteverde Cloud Forest.
In the dry and windy season, the weather is a very local phenomenon. It can change over a few kilometers from dry with a lot of sunshine to misty or even rainy.
Hence, the hypothesis claiming the study domain to be located in a life zone without ecological gradient has certain limitations. Study sites belonging to the continuous habitat tend to be closer to the Cloud Forest than study sites of the fragmented habitat. The closer a forest to the Continental Divide, the more it is under the influence of the moist weather coming from the Atlantic side. On the other hand, the further away a forest from the continental divide, the more it is under the influence of the dry air masses coming from the Pacific.

5 Several models of phytogeography have been proposed by many botanists and naturalists, but one model has been retained and is now actively used in many Latin American countries: L.R. Holdridge's classification system (Janzen 1983). This system is based on mean rainfall and temperature and the seasonal variation and distribution of these two parameters. Floristic characteristics are not considered in the classification. The created units are called “life zones” and have distinctive vegetation physiognomy and structure that can occur in several places on the globe. Holdridge has distinguished 116 different life zones on earth. Costa Rica is structured in 12 life zones.

6 The term “habitat” refers to the forest areas – either continuous or fragmented – serving as habitats for the target understory bird species that have been sampled by Edgardo Arévalo.

2.2 DATA SOURCES

- Topographic map.

  Source: Instituto Geográfico de Costa Rica
  Sheet Nr: 3246 IV, JUNTAS
  Scale: 1:50'000
  Edition: 2-IGNCR 1994
  Projection: Lambert
  Spheroïde: Clarke, 1866 (Ocotepeque)

This map is based on aerial images taken in 1992 by the Instituto Geográfico de Costa Rica.

- Aerial image

  Date: 31.3.1998
  Scale: 1:40'000
  Serial number: Terra 12 - 148
  Company: Hauts-Monts Inc, Canada.
  Region: Juntas, Costa Rica

  Spectral information: three bands: blue (1), green (2) and red (3).
  Image resolution: 2 meters

- Satellite image

  Date: 29.1.2001
  Satellite: Terra Aster
  Spatial information: VNIR
  Resolution. 15 m

The satellite image has been discarded because of the unfavorable position of clouds over the study area.

- Bird data and site coordinates

The bird data has been collected by José Edgardo Arévalo using standard mist nets (12 m long by 2.6 m height, 36 mm mesh). Birds have been captured using the nets placed in lines and from ground level to 2.5 m. The nets have been placed in patches of primary forest[7]. The daily sampling time is usually 4 hours, from 6am to 10am. The captured birds are identified, ringed, weighed and measured. However, the data set required for this project consists of a sub-part of the whole data collected by Edgardo Arévalo containing richness and abundance of the species captured at each site, the net time effort, and the guild, status and habitat of the captured species. The data has been received in form of spreadsheets.
In addition, Edgardo Arévalo has provided the coordinates of the sampling points, acquired by GPS. The sites are always located in patches of mature forest.

7 Consult *4.2 Field approach* for the definition of the Primary Forest class.

2.3 DATA MODELING

The data constituted by landscape models and independent data sources (consult chapter 3.2) has been incorporated in the Geographic Information System Manifold®.

Component	***Data type***
Topograhic map	Image
Aerial image	Image
Landscape models	Grid
Study sites	Vector

Table 1: Data structure of the GIS Manifold®.

The bird data is incorporated as independent tables and linked to the landscape models on the basis of their spatial dimension.
The Fragstats metrics are introduced as attributes to the tables of the landscape models.

3 LANDSCAPE MODELING

3.1 IMAGE ANALYSIS APPROACH

3.1.1 Image rectification

The term “rectification” refers to two processes: rectification and georeferencing. The software used for this process is ERDAS Imagine 8.5.
The raw, untreated information contained in an aerial or satellite image is distorted by both the earth's curvature (relief) and the sensor optic being used. The image **rectification** consists of geometrically correcting the image and resample its information from the initial grid system to a new grid system.
The numerical display of a raw image characterizes every point on the image with a pixel-based X/Y coordinate system. **Georeferencing** is the process of assigning map coordinates to image data. During this process the grid of the image does not change.
The functions applied on the image can be found in appendix 3.

3.1.2 Classification

Image classification is the process of attributing image data to thematic classes such as forests, infrastructure, water bodies, in order to extract this information from the image and to use it for further analysis. This process can either be performed manually - by directly digitalizing the image data - or by using the statistical classification provided by various image analysis software packages.

For this project, a supervised image classification by image segmentation approach has been applied on the above mentioned aerial image. This process has been performed in the ERDAS software extension eCognition®.

As its name indicates, classification by multiresolution segmentation consists of two main steps: segmentation and classification.

Multiresolution segmentation works as a preliminary fragmentation of the image data into homogeneous and small image object primitives. It is based on a region-growing approach starting from one pixel, called the seed, and growing according to a spatial/spectral threshold defined by the user.

In a second step, thematic classes are characterized by choosing samples directly in the image. Each sample (region) consists of several pixels. In the **classification** process, every object primitive is attributed to a class.

In order to get a satisfying output, the spectral signature of the samples should be as narrow as possible and should not overlap. The spectral signatures of the samples are listed in appendix 4.

The values for the parameters used for this analysis can be consulted in appendix 3.

The following interpretation key has conditioned the choice of the samples, by – at the same time – keeping the spectral signature of the samples as narrow as possible.

Class	***Texture***	***Color***
Primary forest	Coarse grained	Dark Water-blue-green
Regrowth	Coarse grained, but less than primary forest	Green-beige-brownish
Grassland	Fine-grained	Light beige-brownish
Urban	None visible	White-yellowish

Table 2: The interpretation key of the classification system of the image analysis approach.

The distinction between primary and secondary forest is not always obvious, whereas urban and grassland can be separated easily by the naked eye.

3.1.3 Filtering

The application of a majority filter on the classified image allows the discarding of stand-alone small patches of aggregated pixels (called the image noise) and other small and narrow elements which would disturb the quantitative analysis of the landscape structure. Furthermore, applying a majority filter leads to an increase in the compactness of the image objects and results in a smoothing of the image information, whereas the pixel size is not changed.

The applied filter is constituted of a 7x7 matrix with the same weight for each component. The matrix is applied on each pixel of the classified image and attributes to each pixel the value of the dominating thematic class in the 7x7 pixel window.

The choice of the size of the matrix has been made after a visual comparison of the 3x3, 5x5, 7x7 and 15x15 with the unfiltered image respectively. Based on the acquired knowledge of the field, the filter with the 7x7 matrix is supposed to represent an apt level of simplification. The main criterion of this choice has been the qualitatively chosen lower limit of structural detail considered apt for this study.

Figure 1: Extract of the unfiltered thematic map.

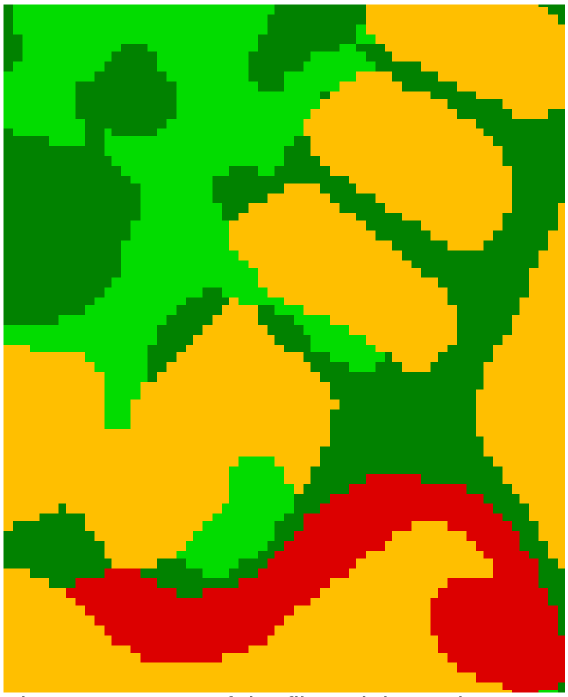


Figure 2: Extract of the filtered thematic map.

The field verification has revealed an error of sometimes more than 300 m between the locations of the study sites on the rectified image and the actual sites in the field. This error is due to the distortion of the coordinates caused by referencing the image to the topographic map which apparently lacks precision. In order to correct the errors, the sites have been relocated on the rectified image with the use of reference points in the field.

3.2 FIELD APPROACH

3.2.1 Field work methods

The field verification of the classified image has revealed an important lack of accuracy of the classification by multiresolution segmentation. The approach of this project is basically a statistical one, but the descriptive analysis of the 14 landscapes is crucial for the general goal of the comparative analysis of species richness and individual abundance versus structure metrics. Although the statistical outputs of the landscape analysis might not be influenced, the descriptive analysis might lack too much of precision.

Therefore, a second classification approach has been adopted consisting of identifying and defining the classes directly in the field. The method used for this work consisted in walking along trails or, where the terrain morphology allowed it, along the patch limits. The rectified image served as reference in the identification process of patch limits. Once identified, the patch limits have been graphically reported on the rectified image.

Where the lack of reference points has made the localization of the patch limits of different classes on the rectified image impossible, the physical extent of the target patches has been identified in the field by measuring distance and azimuth along the patch limits. The tools for this work were meter tape and compass. The acquisition of relative coordinates using GPS has been hindered by high grown vegetation.

A table indicating the sampling efforts and methods for each site can be found in appendix 5.

The 14 landscapes have been digitized using the GIS software ArcView®. Where the patch limits could be identified on the rectified image, the same have been digitized in the GIS. Where the patch limits have been determined by measuring distance and azimuth, the coordinates of the points along the limits have been computed and displayed in the GIS.

As far as connectivity is concerned, only roads larger than 5 meters have been digitized. This threshold translates in some cases an actual physical connectivity of the forest canopy. In the case of absence of physical connectivity, the distance of 5 m is considered to not constitute any hindrance to the species' movement.

Hence, adjoining forest patches of roads with widths below that threshold are considered being connected.

3.2.2 Classification

The field classification approach has allowed the classification to be in more detail, therefore the number of classes is higher than in the old method.

Following classes have been defined:

1. Primary forest. Designates the original forest of different stages of human and cattle intervention. Hosts trees of more than 80 cm stem diameter, and a high number of older lianes of 6 cm diameter, which are good indicators of the undisturbed state of the forest.
2. Secondary forest. Mature regrown forest containing many trees of important diameters, but missing the thick lianes. Trees are of medium height and the forest is characterized by a dense undergrowth. This class identifies the last stage of regrowth, created by either human interventions (deforestation for agricultural or infrastructural use) or natural causes (landslides).
3. Late regrowth. Identifies the second stage of regrowth, i.e. a transitional stage between secondary forest and early regrowth. The vegetation is made up of fast growing species characterized by light wood and big leaves, needing much sunlight. The height of the vegetation is around 5 meters.
4. Early regrowth. Designates the first stage of regrowth consisting mainly of some fast growing species. These species are called “dominant” and reach up to 3 meters of height.
5. Pasture. Area covered by grass species (mainly non-native grass species), sometimes including alone standing trees which do not have an ecological significance either as corridors or as habitat for the understory bird population, hence justifying their inclusion in this class.
6. Agricultural use. Identifies surfaces that are used for any agricultural exploitation including banana and coffee plantations, corn, beans and other vegetables.
7. Seminated trees. Usually consisting of non-native tree species like pines and eucalyptus. They can often be encountered as windbreaks (pines) because of its advantages as a fast growing and wind resisting species. Eucalyptus has been used as main species in private or governmental reforestation projects of larger areas.
8. Urban. Includes infrastructure such as roads and buildings.

The distinction of the different vegetation classes has been based on concerns on the differences of the ecological value of a class. Considering the ecology of the undergrowth bird species, the ecological value of the classes providing a habitat for the target species decreases steadily in the following order:

Primary forest > Secondary forest > Late regrowth > Early regrowth

Since the ecological value of an abandoned plantation is comparable to the one of late regrowth, this type of land use has been attributed to the latter one. However, in order to be able to distinguish the two types of land use, notes have been introduced in the corresponding tables of the GIS.

Seminated trees functioning as windbreaks and some species exploited for agricultural use can provide the birds protection when moving from one habitat to another, hence functioning as ecological corridors.

Considering the temporal restrictions, the sampling of complementary forest structure parameters has been discarded. However, the overall project will not lack this important information since Yúber Rodriguez, forestry engineer, has been charged to collect the necessary data.

As a synthetic overview, the following table presents the disadvantages and advantages of both landscape modeling approaches. The unfiltered thematic map of the image analysis approach has been compared to the field approach characterized by the 8 classes.

Criteria	***Classification by multiresolution segmentation***	***Field classification***
Application on large study areas	apt	Not apt
Rapidity of the process/method	high	low
Potential level of thematic detail	low	high
Descriptive spatial accuracy	high	low
Risk of too high fragmentation level.	high	low

Table 3: The responds of the two different approaches on certain criteria .

The comparative analysis of the statistical outputs of the two landscape modeling approaches requires an identical set of classes. Hence, the 8 classes of the field classification have been melted into the four classes identified in the approach using classification by multiresolution segmentation. In this process, the classes Secondary forest, Early and Late regrowth, Agricultural use and Seminated trees have all been regrouped in a class called Regrowth. The extension of the classes primary forest, pasture and urban has not been changed.

4 STRUCTURAL LANDSCAPE ANALYSIS

The analysis of the landscape structure refers to the study of the landscape composition and configuration. Composition refers to an identification and description of the different ecosystems (classes) present in the landscape. On the other hand, the analysis of the landscape configuration consists of an analysis of the landscape by characterizing it using landscape metrics.

4.1 METRICS SELECTION

The aim of this structural analysis is to describe the landscape patterns in a quantitative way and to verify the basic hypothesis[8] of this study which claims that the 14 landscape can be classified into two different types: the highly fragmented and the more continuous forest.

McGarigal and Marks (1995) proposed a set of over 160 metrics, but evaluating a landscape with the whole set of metrics is not recommended. Most of the indices are correlated and a well-chosen set of some non-redundant indices - adapted to the questions of the study – is enough to characterize the target landscape. Therefore, all the indices selected for this study have a positive correlation smaller than 70%[9] and have been considered relevant for the comparative analysis of species richness and individual abundance versus landscape structure metrics (appendix 6).

The computation of the indices has been performed with Fragstats® (McGarigal and Marks, 1995), a statistical analysis tool, specifically designed and developed to answer the needs of landscape ecology.

The landscape patterns are attributed to three levels: patch (P), class (C) and landscape (L). Each level contributes in a different way to this analysis. Analyzing the landscape allows an overall view on the fragmentation level of the target landscape, whereas analysis on the class level answer questions on a more specific level. Many indices on the landscape or class level are derived from the patch level by summing or averaging over the whole landscape area. However, the interpretation of counterparts of a metric on different levels may slightly differ.

Caution should be applied for the interpretation of many indices since the output of any chosen metric is still function of how the investigator chose to define and scale the landscape (McGarigal and Marks, 1995). Therefore, the choice of basic and simple indices may be of interest. Hence, a good understanding of the metrics is important for a successful application of the latter.

8 Refers to chapter *1.2 Specific Goals.*

9 The choice of a 70% threshold has been based on the correlation thresholds applied in other studies (i.e. see Villard 1998).

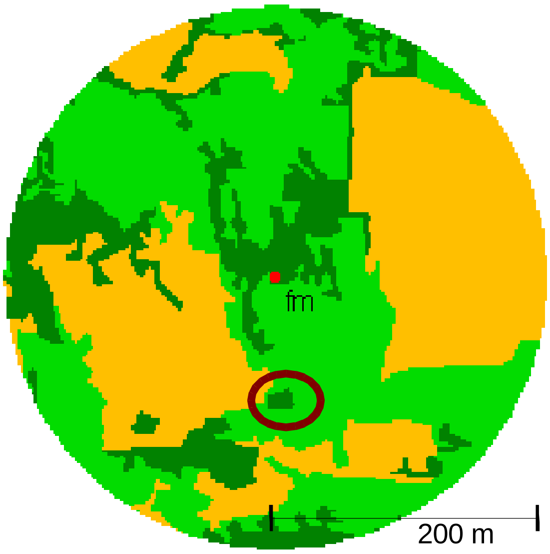
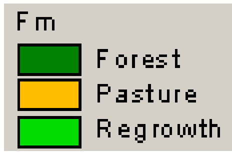


Figure 3: Illustration of the three levels of the landscape pattern analysis.

Landscape: Total circular area.

Class: This landscape is composed of the following three classes.



Patch: Isolated element of a particular class. Marked by

Following metrics have been used in quantifying the landscape structure:

The following 5 indices have been retained:

- Patch density PD (C, L)[10]
- Area AREA (P)
- Shape SHAPE (P, C, L)
- Euclidean nearest neighbor distance ENN (P, C, L)
- Connectance CONNECT (C, L)

Note: For a better understanding of the next paragraphs, the reader is kindly invited to consult the formula sheet in appendix 7, providing detail information on the chosen set of metrics.

The following paragraphs discuss the character and limitations of the chosen metrics and why certain indices have been retained for this study.

10 In brackets the level of landscape pattern to which the specific index is applied to: P: patch, C: class, L: landscape.

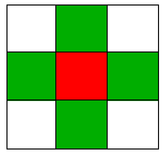
4.1.1 Area/density metrics

Patch density PD and the number of patches NP represent the same information. Patch density is retained since it is an index which is normalized to the area.

Depending on whether the 4-neighborhood or the 8-neighborhood rule is applied, the results of the area index will change. Is the 4-neighborhood applied, two pixels of the same class that are diagonally touching will be considered as separated patches, whereas the same pixels would be considered as part of the same patch if the 8-neighborhood is applied.

Edge as a parameter has not been considered for this study since the quantification of the parameter, in terms of ecological importance, is still a subject of controversy. However, the ecological importance of the edge as an intermediary habitat between primary forest and pasture is not questioned in any way.

4-neighborhood:
Pixels and objects are only defined as neighbors if they share a plane border.



8-neighborhood:
Pixels and objects are defined as neighbors if they are connected by a plane border or a cornerpoint.

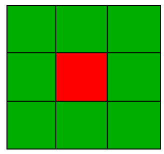


Figure 4: Definition and illustration of the 4- and 8-neighborhood.

4.1.2 Shape metrics

Perhaps the simplest shape index in order to measure the shape of a patch is the perimeter-area ratio. But since this index varies with the patch size, it represents more an edge metric than a shape metric. In order to overcome this dependency problem, the perimeter-shape ratio is compared to a standard shape (square) of the same size.

4.1.3 Isolation/proximity metrics

One crucial parameter for the definition of isolation is scale.

Animal perception of the degree of isolation of fragmented forest is species-dependent (Farina 1998). Hence, habitat patches can become functionally isolated in several ways: The patch edge can have a slightly filtering effect on the movement of certain species in and out of the patch or, on its other extreme, inhibit all kinds of movements of the target species from a patch to its neighboring one. Therefore, in order to make the isolation metric functional[11], the ecology of the target species has to be well-known. In the statistical evaluation of the isolation metric, the ecology of the target species is reduced to one principal parameter: the search radius. This threshold defines the maximum

11 A *functional* metric explicitly measures landscape characteristics which are ecologically relevant, whereas a *structural* metric merely measures the physical composition and configuration of the landscape.

distance at which a neighboring patch should still be included in the statistical calculations.

Errors may occur in the interpretation of the Nearest Neighbor distance (ENN) when the landscape is chosen very arbitrarily (in the view of the target species) and does not include its whole territory. The nearest patch in the landscape may be further away than a patch outside of the defined landscape area. Hence, the landscape should be chosen in a way to include the whole area, i.e. the habitat in which the target species is supposed to move around.

Specifically, the standard deviation (SD) of the ENN distance is a measure of patch dispersion. A small SD relative to the mean ENN distance translates a fairly regular and uniform patch distribution in the landscape, whereas a high SD relative to the mean ENN distance implies a more irregular and uneven distribution of patches.

4.1.4 Connectivity metrics

The connectivity index counts the number of functional joinings between patches or classes. Functional connections can be either a physical link between two patches working as ecological corridor or a threshold distance defined by the distance between two habitats that is still manageable for the target species. The fixing of this threshold to a certain distance is very difficult for many species, since not enough facts are available on their behavior when crossing open areas between patches.

4.2 SCALE CONSIDERATIONS

Observation scale is a factor that influences the output of some of the structure metrics. The application of a filter on a thematic map reduces the sinuosity of the image objects and increases their compactness. Although neither pixel size nor the cartographic scale have been changed, the filter produces a generalization of the image information which leads to a change in the observation scale. Latter does not depend on the actual cartographic scale of a map, but refers to the level of detail a map contains.

5 Results and Discussion

5.1 DESCRIPTIVE STATISTICAL ANALYSIS

The structural landscape metrics calculated for the two thematic maps of different observation scale and for the field approach are compared in a descriptive statistical analysis.

In a landscape structure analysis, all the chosen metrics work as means to characterize – considering their limitations, to a certain extent – the landscape pattern, and therefore dissimilarities as well as similarities are important in the study. In a comparative analysis, landscape pattern versus bird diversity, this can change, however does not have to. Considering a species A present in the fragmented habitat type and a species B present in the continuous habitat. In order to find the factors responsible for their limited presence in the two habitats, the dissimilar metric outputs may be of greater interest than the similar metric results. In other words, a parameter x showing the same values in both habitats may not be a useful discriminative indicator for the differences in presence of the two species. However, this does not exclude parameter x to be a characteristic landscape parameter for species A and species B respectively.

Two parameters have been defined for the following two metrics:

Metric	***Metric subgroup***	***Parameter***	***Value***
Euclidean Nearest Neighbor distance ENN	Isolation	Search radius	10 m
CONNECT	Connectivity	Threshold distance	10 m

Table 4: The user defined parameters for the isolation and connectivity metrics.

The choice of these parameters is based on the ecology of the target species, according to the advice of José Edgardo Arévalo. However, the general lack of knowledge in this scientific field implies a certain randomness in the choice of this parameter.

In the graphical representations of the results of the quantitative structural analysis, the sites have been regrouped according to their habitat type. The first seven sites are situated in the more fragmented habitat, whereas the other seven sites are located in the more continuous habitat.

Summary statistics of the computed metrics can be consulted in appendix 8, 9, and 10.

Study site	**Habitat**
AH	Fragmented
FI	Fragmented
FM	Fragmented
FMI	Fragmented
MR	Fragmented
RB	Fragmented
VT	Fragmented
BA	Continuous
BT	Continuous
FB	Continuous
HH	Continuous
JS	Continuous
RC	Continuous
WV	Continuous

Table 5: The 14 study sites and their relative habitat type.

5.1.1 Image analysis approach

Landscape level

The qualitative analysis shows the following distribution and proportions of the classes in the 14 landscapes. The total area of a landscape equals 12.5 ha.

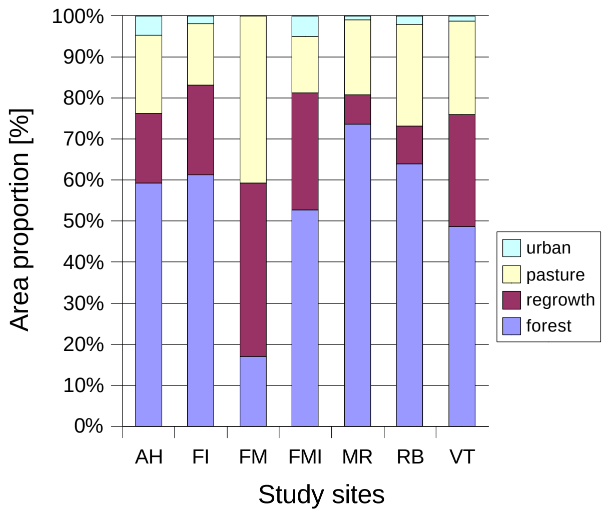


Figure 5: Area proportion of the 4 classes of the 7 sites in the fragmented habitat. Analysis on the landscape level of the unfiltered thematic map of the image analysis approach.

Figure 5 and 6 illustrate the distribution of the classes in the 14 landscapes of the unfiltered thematic map. There is a clear dissimilarity in the percentage of forest cover of the two habitat types. The mean forest cover of the fragmented habitat corresponds to 54% of the landscape area and the one of the more continuous habitat attains 86%. Hence, it is the dominant class in both habitat types. The surface attributed to urban infrastructure is comparable in both the habitat types, too. Both classes regrowth and pasture occupy a comparable surface area (22% and 5% & 7% respectively) within both habitat types, however with a difference of 15%.

	Mean F habitat [%]	SD F habitat [%]	Mean C habitat [%]	SD C habitat [%]
Forest	54	2.3	86	1.1
Regrowth	22	1.5	5	0.8
Pasture	22	1.2	7	0.4
Urban	2	0.2	2	0.2

Table 6: Mean percentage values and standard deviations of the class proportions in the fragmented (F) and continuous (C) habitat. Analysis on the landscape level of the unfiltered thematic map of the image analysis approach.

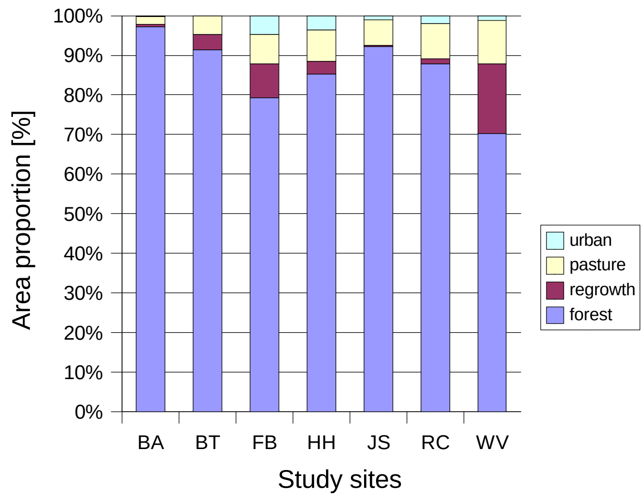


Figure 6: Area proportion of the 4 classes of the 7 sites in the continuous habitat. Analysis on the landscape level of the unfiltered thematic map of the image analysis approach.

The classes distribution does not change much from the unfiltered to the filtered thematic map. Hence, the graphical illustration of the classes distribution of the filtered thematic map has been discarded.

	F habitat [%]	SD F habitat [%]	C habitat [%]	SD C habitat [%]
Forest	54	2.4	87	1.1
Regrowth	24	1.4	5	0.7
Pasture	19	1.3	6	0.4
Urban	2	0.2	2	0.2

Table 7: Mean percentage values and standard deviations SD of the class proportions in the fragmented (F) and continuous (C) habitat. Analysis on the landscape level of the filtered thematic map of the image analysis approach.

Table 8 illustrates the difference of class distribution between the unfiltered map and the filtered map. The forest cover increases in both habitat types, whereas the surface of urban infrastructure decreases. In the fragmented habitat the regrowth increases, whereas it decreases in the continuous habitat. Pasture cover decreases in both habitat types, even though at a different percentage rate (-2.9 % and -0.5 % respectively).

	F habitat [%]	C habitat [%]
Forest	0.5	1.1
Regrowth	2.1	-0.3
Pasture	-2.9	-0.5
Urban	-0.2	-0.2

Table 8: Difference of the mean percentage values - between the unfiltered and the filtered thematic map - of the class proportions of the fragmented (F) and the continuous (C) habitat. Positive values indicate an increase in the class proportion from the unfiltered to the filtered map, whereas negative values indicate a decrease. Analysis on the landscape level.

These differences can be explained as follows:

The area of the forest class includes many small and isolated patches of the other classes which - in the process of filtering - get incorporated in the forest class. Pasture is often present in isolated patches surrounded by forest and hence get incorporated in the forest class. The patches of the urban class are often narrow and their area gets lost to surrounding patches that are more compact. The class regrowth in the fragmented habitat is present in more compact patches than in the continuous habitat which leads to their incorporation by the forest class, too.

Note: The error bars in the following graphs refer to the standard deviations SD of the mean values.

Patch density

In both the filtered and the unfiltered thematic map, the patch density is relatively less important in the landscapes of the less fragmented habitat than in the ones of the more fragmented habitat. With a patch density of 273 patches per 100 ha of the unfiltered thematic map, the mean patch density of the latter is greater than of the filtered (260). This is an expected implication of the applied filter.

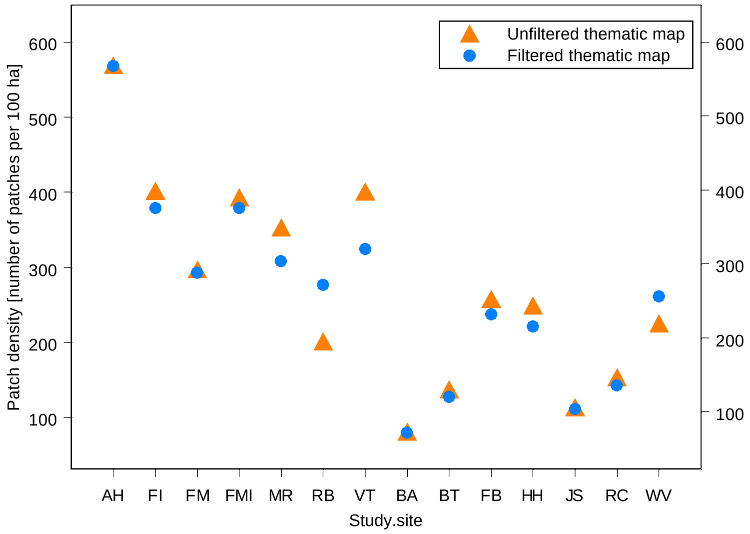


Figure 7: Behavior of the patch density metric on the landscape level, for the unfiltered and filtered thematic map.

Mean patch shape

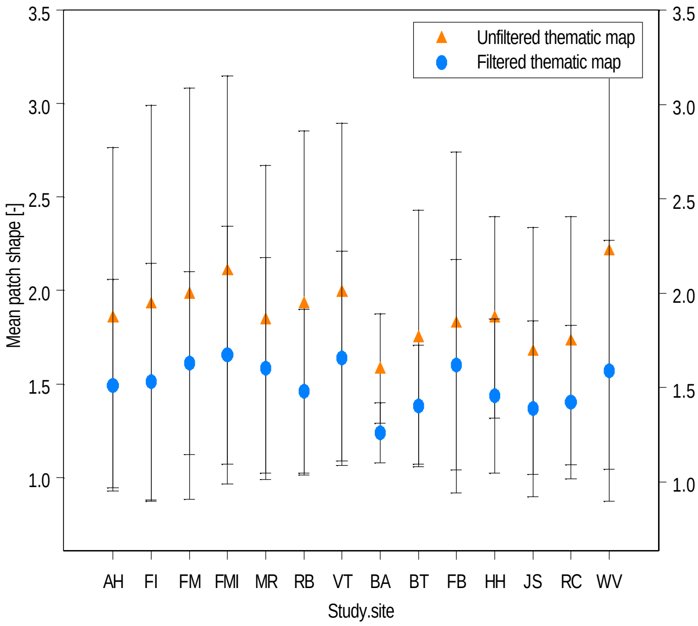


Figure 8: Behavior of the shape metric on the landscape level, for the unfiltered and filtered thematic map.

The mean shape value, representing a normalized measure of the patch perimeter-surface ratio, does not discriminate any important dissimilarities between the more continuous and the more fragmented habitat. On the level of the two different scales, the mean shape value of the filtered map is constantly below the one computed for the unfiltered map. The level of shape complexity of the image objects of the filtered map has decreased. The standard deviation which works as an index of the number of patches, is greater in the more fragmented habitat than the less fragmented one, and is therefore confirming the results of the patch density metric.

Euclidean Nearest Neighbor distance

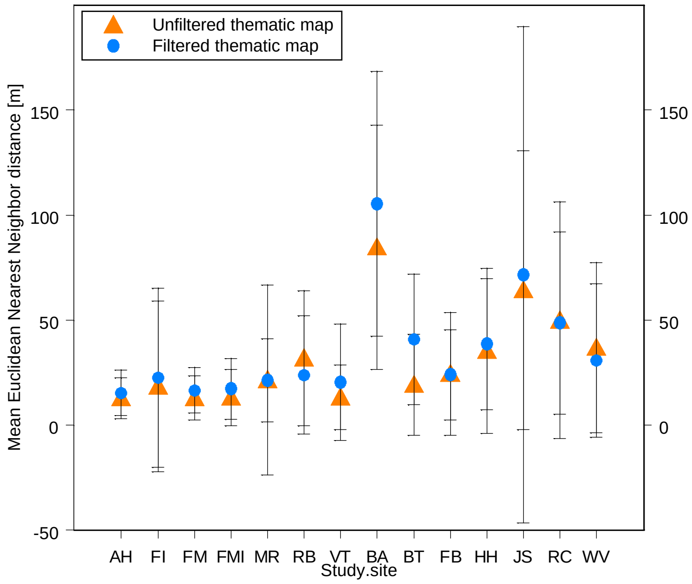


Figure 9: Behavior of the ENN metric on the landscape level, for the unfiltered and filtered thematic map.

The values of the ENN distance indicate the ENN mean to be greater in the less fragmented habitat than in the more fragmented one. In addition, the standard deviation of the index is important - relatively to the mean distance - for both habitat types which translates an irregular and uneven distribution.

	Mean ENN unfiltered [m]	SD unfiltered [m]	Mean ENN Filtered [m]	SD filtered [m]
Fragmented	17.8	23.8	19.6	22.1
Continuous	28.0	30.7	32.5	29.5

Table 9: Mean values of the Mean Euclidean Nearest Neighbor distance and the standard deviation of the index on the landscape level, for the unfiltered and the filtered map.

The mean ENN of the filtered thematic map is slightly greater than the ones of the unfiltered thematic map. The increase in compactness of the image objects in the filtered map has increased the edge-to-edge distances - the parameter based on which the metric is computed - between the objects.

Connectivity

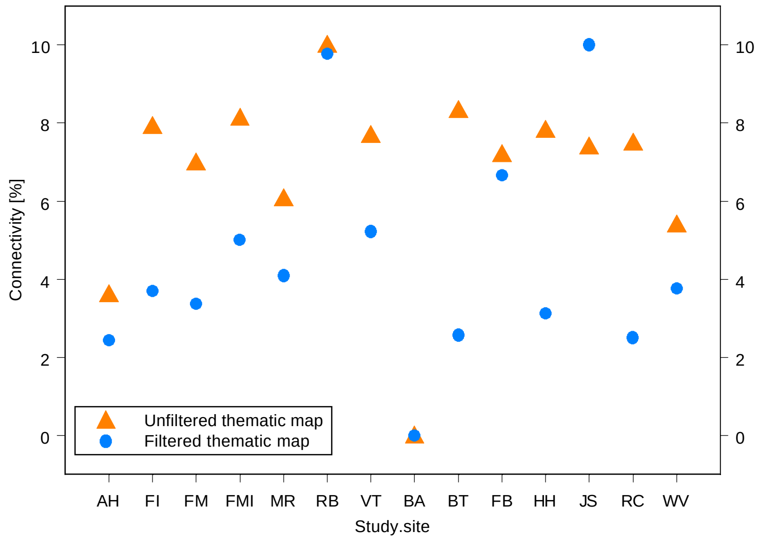


Figure 10: Behavior of the connectivity metric on the landscape level, for the unfiltered and filtered thematic map.

The connectivity values do not indicate a dissimilarity between the two types of habitat, but between the two scales. The connectivity values of the filtered map are smaller than the ones of the unfiltered one. However, even the latter ones are minimal (up to 10 %) considered the maximum of this index of 100 %.

Caution has to be applied when interpreting this index. Low index values refer to a low connectivity in the sense that a small percentage of the patches present in the landscape are connected. But this statement can lead to misinformation when the index is characterizing a landscape that consists of two continuous patches, for example a forest patch and a pasture patch, whose whole extent are not included in the landscape. In this case, the connectivity index will be small, but the actual connectivity is maximal, in the sense that only one patch is present. The ecological conditions for many forest dwelling species may be much better in one continuous forest patch, than in a landscape consisting of a high number of forest patches with a maximal connectivity.

Class level

Since the habitat of our target species is situated in the forest class, the structural analysis on the class level concentrates on this type of land cover.

Patch density

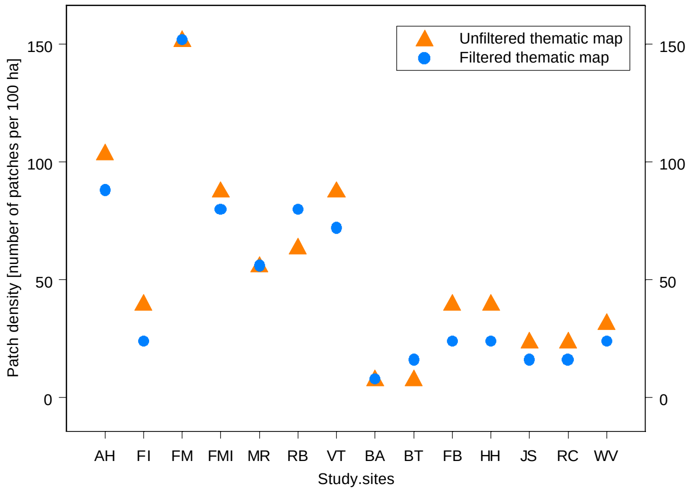


Figure 11: Behavior of the patch density metric on the class level, for the unfiltered and filtered thematic map.

For both thematic maps, the patch density is significantly smaller in the less fragmented habitat than in the more fragmented one. However, the unfiltered map indicates with a mean patch density of 54.86 patches per 100 ha a slightly more fragmented habitat than the filtered map with 48.56 patches per 100 ha. The applied 7x7 majority filter has discarded some of the smaller patches in the landscape.

Shape

As far as the shape value is concerned, there is no clear dissimilarity between the the two different types of habitat. This indicates that the shape complexity of the patches is similar in both fragmented and continuous forest. However, the generalization effects of the filter are translated by a reduction of the mean shape value of the filtered image from 1 to 0.7. As mentioned above, the standard deviation of this metric represents a similar information as the number of patches, in this case a smaller level of fragmentation of the continuous habitat.

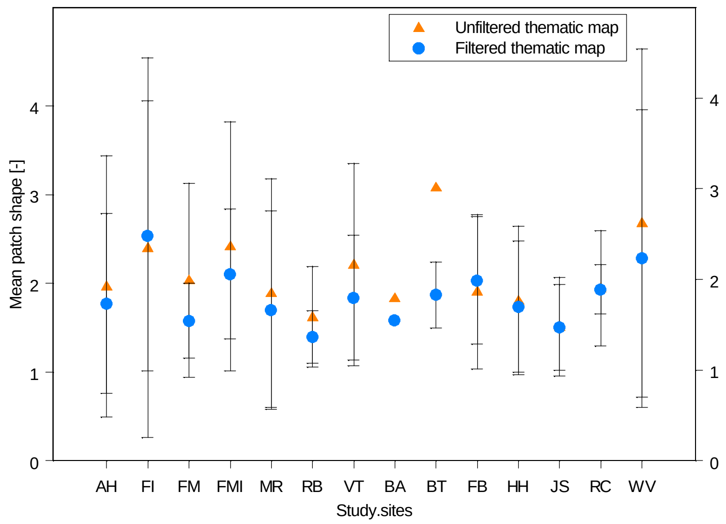


Figure 12: Behavior of the shape metric on the class level, for the unfiltered and filtered thematic map.

Euclidean Nearest Neighbor distance

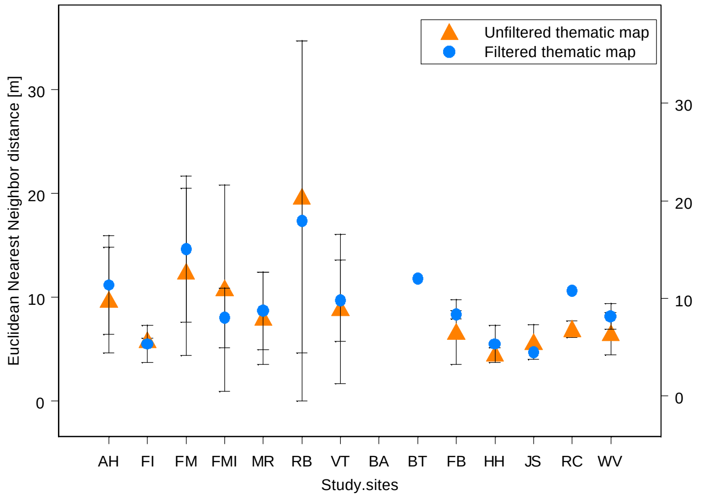


Figure 13: Behavior of the ENN distance metric on the class level, for the unfiltered and filtered thematic map.

The mean ENN distance is greater in the less fragmented habitat than in the more fragmented one. Compared relatively to the mean distance, the standard deviations of the metric of both unfiltered and filtered map in both fragmented and continuous habitat is small which translates a more regular and uniform distribution of the forest patches.

	Mean ENN unfiltered [m]	SD unfiltered [m]	Mean ENN Filtered [m]	SD filtered [m]
Fragmented	9.5	6.1	9.5	5.7
Continuous	10.8	7.2	10.9	6.3

Table 10: Mean values of the Mean Euclidean Nearest Neighbor distance and the standard deviation of the index on the class level, for the unfiltered and filtered map.

Connectivity

No dissimilarity is discriminated for the connectivity metric, either on the level of the habitat type or at the level of the two different thematic maps.

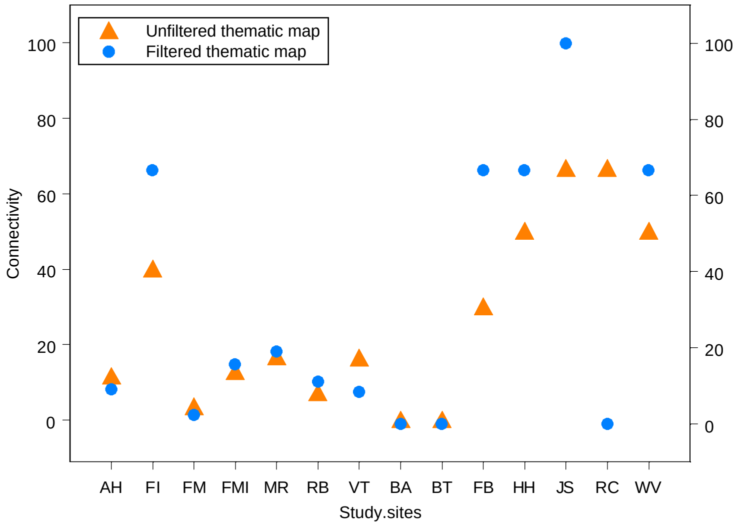


Figure 14: Behavior of the connectivity metric on the class level, for the unfiltered and filtered thematic map.

Patch level

In order to know more about the forest patch where the mist nets are placed, the structural analysis on the patch level is restricted to these target patches.

Area

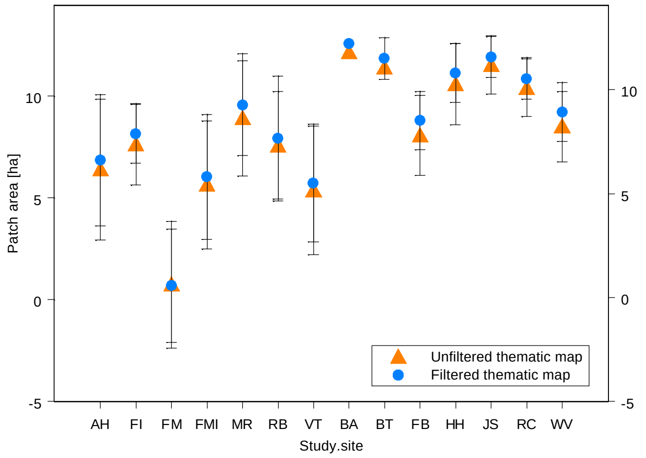


Figure 15: Behavior of the area metric on the patch level, for the unfiltered and filtered thematic map.

The area of the target patches is greater in the continuous habitat than in the more fragmented one. The standard deviation of this metric represents a standard deviation from the class mean. Hence, it indicates if the area of the target patch is a mean sized patch of its class or if its size stands out of the mean. On the level of the two map types, the application of the majority filter results in an increase in patch size. This indicates that the gain in area of the target patch by assimilating small patches situated inside the patch (such as small clearances) is more important than the loss of areain form of narrow excrescences (such as windbreaks linked to the main patch).

Shape

The mean shape complexity metric does not show any dissimilarity on the level of the two habitat types. The dissimilarities of the standard deviation between the two habitats indicate the difference in the state of important fragmentation of the forest class.

The decrease of the shape complexity value from the unfiltered to the filtered map reflects the effect of generalization of the majority filter on the image objects.

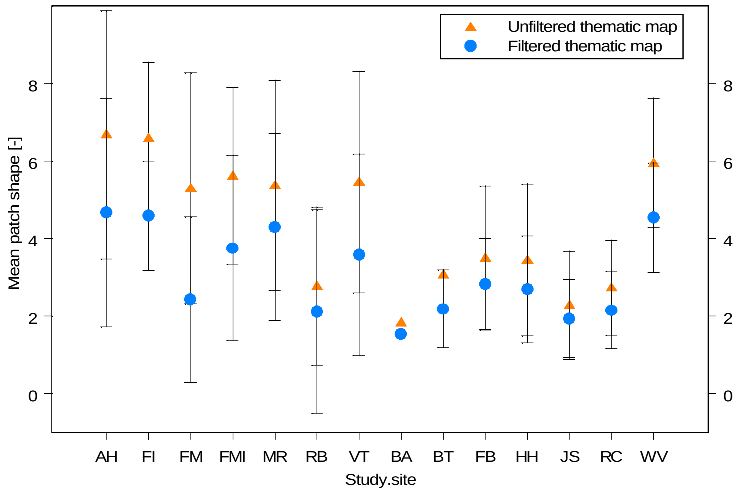


Figure 16: Behavior of the shape metric on the patch level, for the unfiltered and filtered thematic map.

ENN distance

No dissimilarity is discriminated by the ENN distance metric on the patch level.

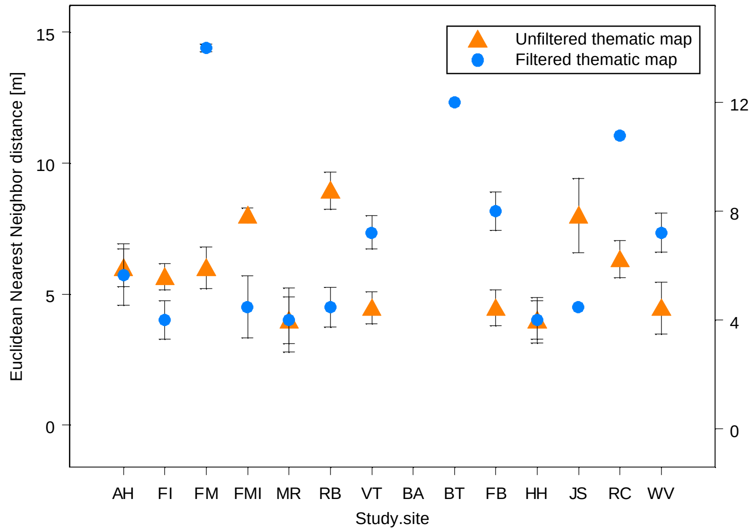


Figure 17: Behavior of the ENN distance metric on the patch level, for the unfiltered and filtered thematic map.

Scale implications

Metric	Landscape	Class	Patch
Area	---	---	↑
Patch density	↓	↓	---
Shape complexity	↓	↓	↓
ENN	↑	→	-
Connectivity	↓	-	---

Table 11: The development of the metrics - on the landscape, class and patch level - from the unfiltered to the filtered thematic map.

Legend:

↑ value increases

↓ value decreases

→ value does not change

- no development discernible

--- no computations for this metric

The application of a filter is likely to influence the output of the landscape structure metrics. Table 11 summarizes the general development of the metrics when applying the majority filter.

It is important to note that any conclusion made on the basis of the outputs of this analysis are valid for the conditions of this case study only. Changes in image resolution or study area extent influence the metrics in a way that has not been studied in this work.

What are the implications of scale for the comparative analysis of species richness and individual abundance versus landscape metrics? Which tendencies of the output of the scale sensitive metrics are favorable for the analysis output?

The aim of the comparative study is to examine if and to what extent forest fragmentation influences species richness and individual abundance. The tools for this analysis are the landscape structure metrics. Therefore, an accentuation of dissimilarities of the metric outputs between the two habitat types is of advantage for this study. The easier the discrimination of a positive correlation between the two habitat types and the relevant metrics, the clearer the outputs of the comparative analysis.

A second pertinence criterion is the absolute numeric value of the metric output. Small numeric values make an understanding and interpretation of the metric easier.

In terms of the scale implications study, each metric has to be examined if the application of a filter implies any advantage in terms of metric pertinence.

AREA	Good discrimination between the two habitat types. Slight increase in the values which does constitute neither advantage nor disadvantage.
PATCH DENSITY	Regrouping effect within the habitat type on both the landscape and the class level.
SHAPE COMPLEXITY	Weak value discrimination between the two habitat types with both filtered and unfiltered thematic map.
ENN DISTANCE	Passing from the unfiltered to the filtered map, the difference in the mean ENN values increases at a similar standard deviation.
CONNECTIVITY	The metric does not show any dissimilarity between the two habitat types.

The following table summarizes the results.

Metric	Filter implications
Area	➔
Patch density	🡅
Shape complexity	➔
ENN distance	🡅
Connectivity	➔

Legend.

🡅 positive implication

➔ neither positive nor negative implication

Table 12: Summary of the filter implications for the different metrics.

The filter did have only positive or neutral implications. In the cases where the filter did not bring any advantage, the results on the unfiltered map show the inaptness of the particular metrics. Hence, the application of a filter can be recommended.

5.1.2 Field approach

Landscape level

The method of the field approach allows an improvement of the detail represented by the landscape model and hence its level of information.

The absolute values of the area proportions can be consulted in appendix 11.

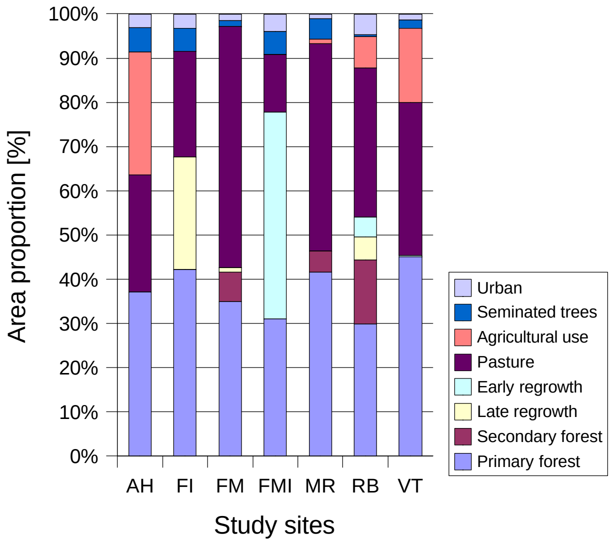


Figure 18: Area proportion of the 8 classes of the 7 sites in the fragmented habitat. Analysis on the landscape level of the field approach.

The Primary Forest class is distributed regularly among the 14 sites in the fragmented area, whereas in the more continuous one the proportions of primary forest show important variations. Study sites FB and WV are characterized by a primary forest cover comparable to the sites of the fragmented habitat. Both sites are surrounded by large areas of pasture. When evaluating species richness and individual abundance vs landscape structure metrics, these uneven ecological conditions have to be considered.

The hypothesis on which has been based the choice of the study site location claims the mean forest cover of the fragmented habitat to be between 30% and 40 % and the one of the more continuous habitat to be between at least 60% and 70% (refer to *1.3 Specific goals*). The results of the field approach confirm this hypothesis (table 13). The mean forest cover of the fragmented and the continuous habitat measures 37% and 70% respectively. But sites FB and WV introduce an important bias. The mean forest cover of the continuous habitat computed by excluding these two sites reduces the standard deviation from 3.0 to 0.7. The resulting forest cover measures 84%.

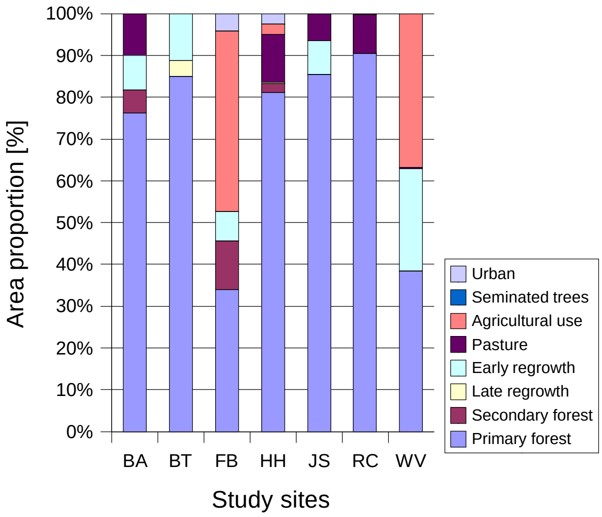


Figure 19: Area proportion of the 8 classes of the 7 sites in the continuous habitat. Analysis on the landscape level of the field approach.

CLASS	Mean F habitat [%]	SD F habitat [%]	Mean C habitat [%]	SD C habitat [%]	C habitat* [%]	SD C habitat* [%]
Primary forest	37	0.7	70	3.0	84	0.7
Secondary forest	4	0.7	3	0.6	2	0.3
Late regrowth	5	1.2	1	0.2	1	0.2
Early regrowth	7	2.2	8	1.0	6	0.7
Pasture	33	1.8	5	0.6	7	0.6
Agricultural use	8	1.4	12	2.4	0	0.1
Seminated trees	3	0.3	0	0.0	0	0.0
Urban	3	0.2	1	0.2	1	0.1

Table 13: Class proportions in the fragmented (F) and continuous habitat (C) for the Field approach. The star * in the third column indicates the class proportions of the continuous habitat without the values of sites FB and WV.

In order to compare the metrics of the field approach with the ones of the image analysis approach, the number of classes had to be reduced.

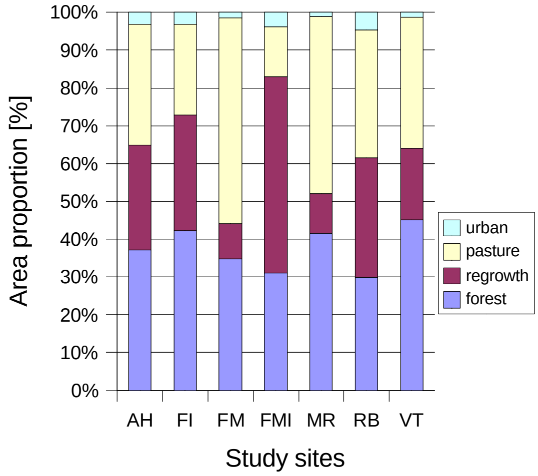


Figure 20: Area proportion of the 8 classes of the 7 sites in the fragmented habitat. Analysis on the landscape level of the field approach and the image analysis approach.

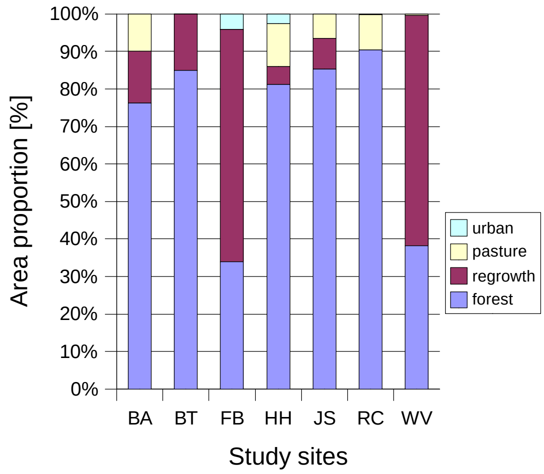


Figure 21: Area proportion of the 8 classes of the 7 sites in the continuous habitat. Analysis on the landscape level of the field approach and the image analysis approach.

	Mean F habitat [%]	SD F habitat [%]	C habitat [%]	SD C habitat [%]
Forest	37	0.7	70	3.0
Regrowth	26	1.8	24	3.3
Pasture	34	1.7	5	0.6
Urban	3	0.2	1	0.2

Table 14: Classes proportions of the regrouped field approach for the fragmented (F) and the continuous (C) habitat.

5.2 COMPARATIVE ANALYSIS OF IMAGE ANALYSIS APPROACH VS. FIELD APPROACH AND OF THE FRAGMENTED VS. THE CONTINUOUS HABITAT

5.2.1 Visual analysis and the problem of scale

The level of structural detail of the image analysis approach seems to be greater than the one of the field approach. The melting of the 8 thematic classes has even more diminished the patchiness of the field approach. However, accent has to be laid on the difference between the level of structural detail and the so-called ground truth. The image treatment approach might represent better the actual patchiness of the study areas, hence the structural detail, whereas the field approach can better represent the thematic detail[12]. The spectral signatures of the samples of the thematic classes are sometimes overlaying which results in a weaker level of ground truth.

But can the two approaches been compared as easily? Do not the basic differences in the two methods impede a direct comparison?

There are crucial differences in the methods of the two approaches. Each one presents subjectivities, but at different levels and to different extents. But the basic problem is scale and the subjectivity it implies.

The upper and lower limits of scale, the landscape extent and the pixel size, are the same for the two approaches and they have not been changed during the study. What is different in these two approaches is the observation scale. In the image treatment approach, the decision maker chooses the observation scale by choosing the level of simplification gained by the filter application. The aim of the latter one is to reduce the complexity of the image objects to a lower limit apt for the current study. In the field approach[13], the notion of scale is important during the process of patch delimitation in the field, as well as during the process of digitizing.

5.2.2 Dependency analysis of the image and the field approach and of the two habitat types for the class area distribution

The question is: “For the class area distribution, is there a dependency between the field and the image treatment approaches?”

This analysis is based on linear regression models and has been made for the four defined classes of the two approaches (Appendix 13). For the forest class, the results show a highly significant correlation between the two approaches (p = 0.0036). However, the intensity of the correlation is not very high (R^2 = 0.520). The correlation of the two approaches for the regrowth class however is not significant. This might be due to the differences in the classification system that are very important for the regrowth class. Vegetation that can be classified as regrowth in the field has often a very similar

12 For this comparative analysis, the initial 8 classes have been melted down to 4. Hence, in this case the field approach does not give any advantage in the subject of thematic detail. However, it is important to remember that the field approach carries the potential for a high level of thematic detail.

13 The observation scale of the field approach is approximately 1:5000.

spectral signature to vegetation classified as forest. This also explains the poor correlation intensity of the forest class. For the pasture class, the correlation between the two approaches is highly significant and intense (p = 0.00003, R^2 = 0.768). This is due to the clear delimitation of the pasture areas in the classification methods of both approaches. On the level of the urban class, the correlation between the two approaches is highly significant (p = 0.0026), but not intense (R^2 = 0.544). This is due to the similarities in the spectral signature of the pasture and the urban class. The intensity of the correlation of the pasture class is less influenced by this unclarity, because the proportion of this class in the landscape is much more important than the one of the urban class. The same effect can be noted for the forest and the regrowth class.

A second question is: “For the area of the forest class, is there a difference between the fragmented and the continuous habitat?”

This is analyzed by using the Wilcoxon rank-sum test. The reader is kindly invited to consult appendix 17 for details.

The zero hypothesis of the equal means is discarded (p = 0.0004), hence there is a significant difference between the values of the patch density metrics of the two approaches. The mean forest area in the fragmented habitat (mean = 5.70 ha) is much smaller than in the continuous habitat (mean = 9.67).

5.2.3 Metric analysis

This chapter is dedicated to the comparative analysis of the landscape structure metrics of the thematic map produced by the field approach, and the filtered thematic map received by image analysis approach.

The aim of this chapter is to determine to which extent the chosen metrics discriminate the dissimilarities of the two approaches and which approach is the more apt for the comparative bird species analysis.

It is important to mention that the decision between the two approaches can not solely based on metric outputs, but is subject of an important number of temporal and financial limitations. The field approach demands a great time investment and therefore may not be apt when the study area exceeds a certain extent.

The reader is kindly invited to refer to appendix 12 for the illustration of the 14 landscapes of the compared approaches.

Landscape level

Patch density

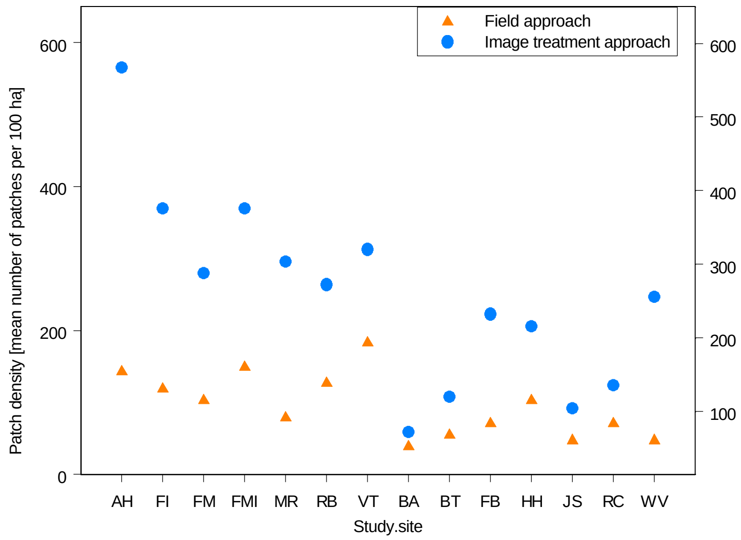


Figure 22: Behavior of the patch density metric on the landscape level, for the field approach and the image analysis approach.

Patch density discriminates a clear dissimilarity between the two habitat types on the level of the two approaches.

The patch density of the field approach is significantly smaller than the one of the image analysis approach. Considering that the melting of the classes of the field approach may induce an important reduction of the patch density, the actual state of fragmentation might lie between the values of the two approaches.

Shape

The values of the patch shape metric do not indicate any significant dissimilarity between the two habitat types (table 15).

The mean values of the image analysis approach are systematically smaller than the ones of the field approach. This is due to the normalization[14] of the perimeter-surface ratio. The shape metric compares any patch shape of a square.

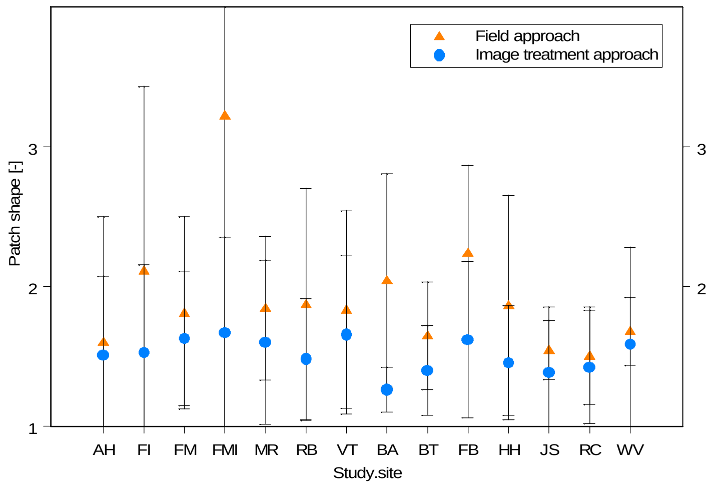


Figure 23: Behavior of the shape metric on the landscape level, for the field approach and the image analysis approach. In the attention to better discriminate the dissimilarities, the range of the mean shape values has been reduced and the minimum set to 1 which is the shape value for a square.

14 The perimeter surface ratio is normalized to a square by multiplying the perimeter by 0.25 and dividing it by the square root of the surface.

Hence, two patches of different size but with the same perimeter-surface ratios can have very different shape metric values[15]. The shapes of the image objects of the image analysis approach are closer to squares than the ones of the field approach. The high mean shape value of site FMI is due to the long and narrow patches of the windbreaks and the road.

	Mean Shape unfiltered [-]	SD unfiltered [-]	Mean Shape filtered [-]	SD filtered [-]
Fragmented	2.04	1.09	1.58	0.56
Continuous	1.79	0.48	1.45	0.43

Table 15: Mean ENN distance values and the mean standard deviations of the metric on the landscape level, for both field and image analysis approach and both the habitat types.

ENN distance

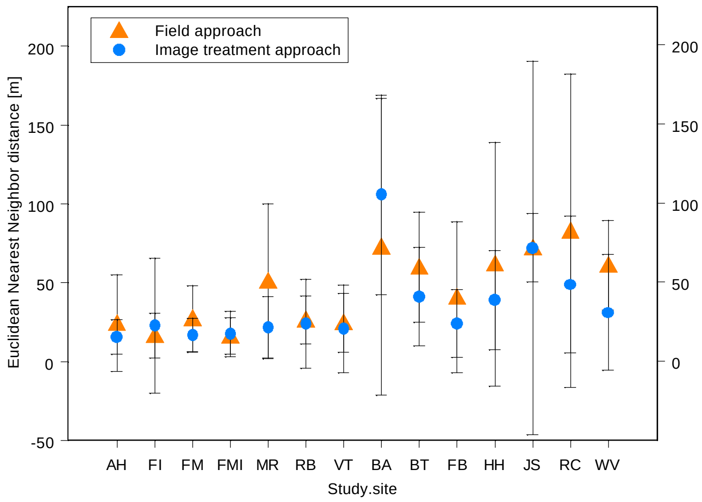


Figure 24: Behavior of the ENN distance metric on the landscape level, for the field approach and the image analysis approach.

The mean ENN values of both thematic maps are greater in the continuous habitat than in the fragmented one. The distances between patches of the same class in the fragmented area are smaller than in the continuous habitat. The standard deviation - compared to the mean ENN value - is important in both the field and the image treatment approach indicating a relatively irregular patch distribution in both habitats. The mean ENN values of the image analysis approach are slightly smaller than the ones of the field approach.

15 The shape metric values for patch 1 (perimeter = 100, surface = 100) and for patch 2 (perimeter = 20, surface = 20) are respectively 2.5 and 1.14.

	Mean ENN Field [m]	SD Field [m]	Mean ENN Image [m]	SD Image [m]
Fragmented	26.67	22.89	19.62	22.07
Continuous	64.54	57.61	51.4	49.21

Table 16: Mean ENN distance values and the mean standard deviations of the metric on the landscape level, for both field and image analysis approach and both the habitat types.

Connectivity

No dissimilarity is observed either between the two habitat types or between the two approaches.

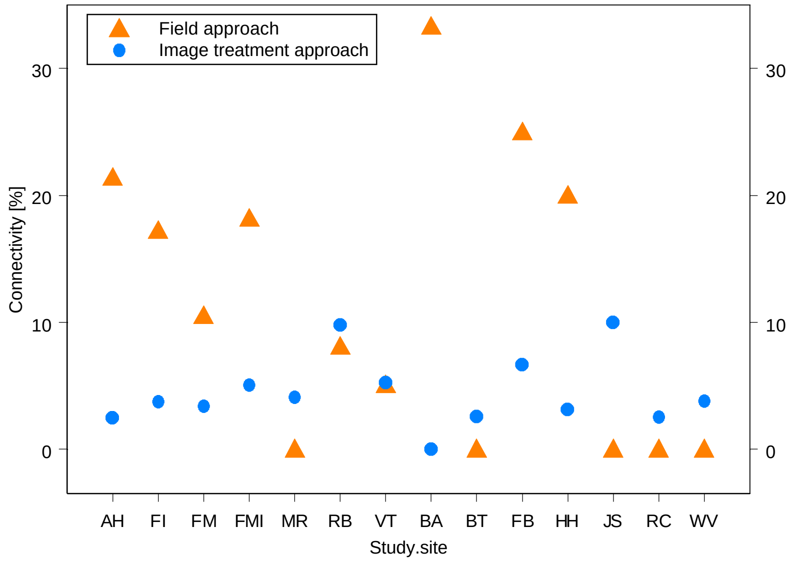


Figure 25: Behavior of the connectivity metric on the landscape level, for the field approach and the image analysis approach.

Dependency analysis

The question is: “For the metrics on the landscape level, is there a dependency between the field and the image treatment approaches?”

This is analysed by using linear and quadratic regression models. The details of this analysis can be found in appendix 14.

For the patch density and the ENN metrics, the results of the two methods are significantly related (p = 0.00245 and p = 0.002587). However, the intensity of their correlations is week (R^2 = 0.549 and R^2 = 0.545 respectively). The correlations of the shape and the connectivity metrics are insignificant. This means that field and image treatment approaches tend to give similar estimation of patch density and ENN, but not of shape and connectivity. Because of lack of time, the reasons of these results could not be analyzed.

A second question is: “For the patch density metric on the landscape level, is there a difference between the fragmented and the continuous habitat?”

This is analyzed by using the Wilcoxon rank-sum test. The reader is kindly invited to consult appendix 18 for details.

The zero hypothesis of the equal means is discarded (p = 0.0018), hence there is a significant difference between the values of the patch density metrics of the two approaches. The mean patch density of the fragmented habitat (mean = 243) is much greater than of the continuous habitat (mean = 112).

Class level

Patch density

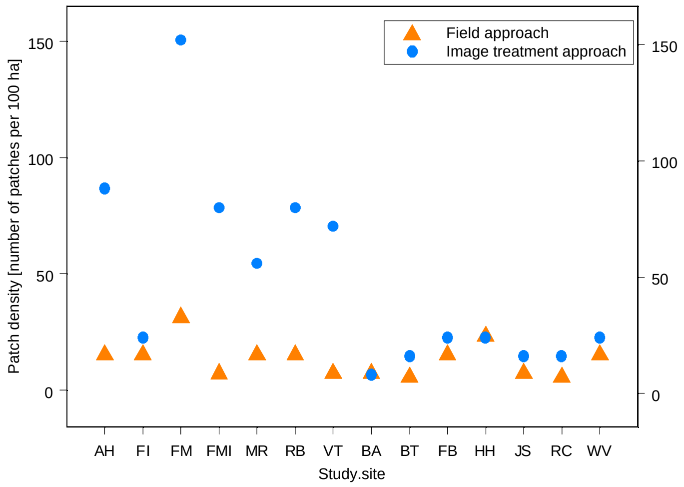


Figure 26: Behavior of the patch density metric on the class level, for the field approach and the image analysis approach.

Only the image analysis shows a dissimilarity between the two habitat types.

The forest patch density of the field approach is systematically lower than the one of the image analysis approach. This might be due to differences in the classification system of the two approaches.

Patches attributed to the class of “agricultural use” or “seminated trees” in the field approach are characterized by a spectral signature close to that of the primary forest.

Hence, in the image analysis approach these areas have been attributed to the forest class which results in an increase in the patch density of the fragmented habitat. The effect is not present in the second habitat type, because the relative importance of the forest area is greater and the agriculturally used area and the reforested area are less important. In the field approach, these land use types are separated from the forest class and the patch density becomes more uniform.

In the image treatment approach, the highly fragmented primary forest of study site FM leads to an important patch density value. The spectral signature of this forest patch is very close to the one of a secondary forest which results in a dominance of the latter class. The presence of the primary forest class is reduced to small patches within the secondary forest class.

Shape

On the level of the two habitat types, no significant dissimilarity is observed. The dissimilarity between the two approaches is slightly greater. The mean shape value is higher for the field approach than for the image approach. The same dissimilarity has been observed for the landscape level.

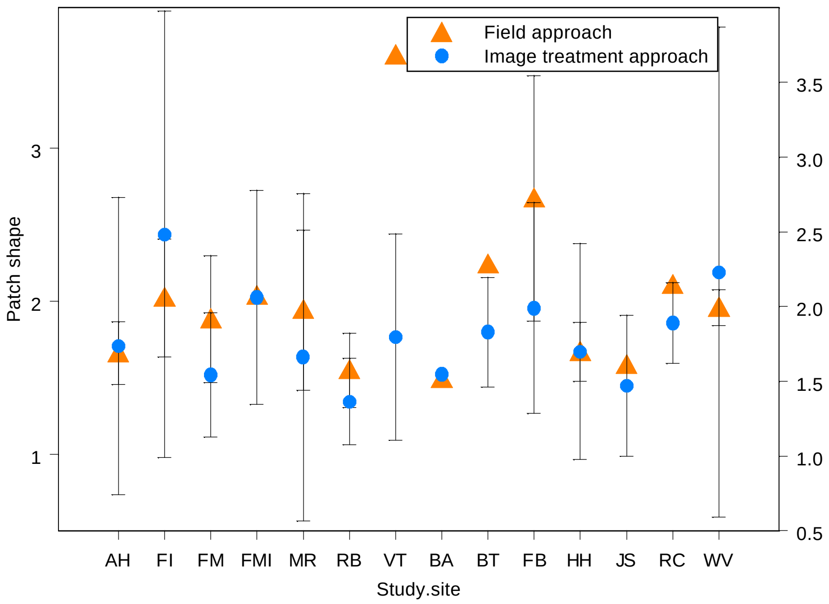


Figure 27: Behavior of the shape metric on the class level, for the field approach and the image analysis approach.

	Shape Mean Field [-]	SD Field [-]	Shape Mean Image [-]	SD Image [-]
Fragmented	2.1	0.3	1.81	0.8
Continuous	1.96	0.2	1.81	0.6

Table 17: Mean shape values and the mean standard deviations of the metric on the class level, for both field approach and image analysis approach and both the habitat types.

ENN distance

No dissimilarity is observed either between the two habitat types or between the two approaches.

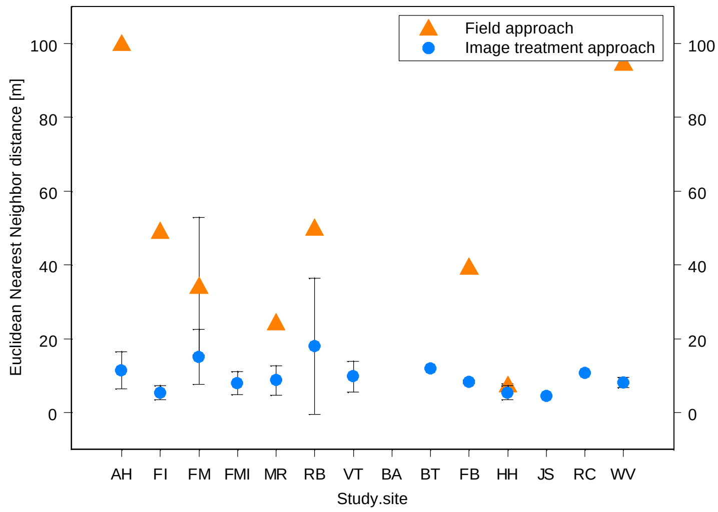


Figure 28: Behavior of the ENN distance metric on the class level, for the field approach and the image analysis approach.

Connectivity

No dissimilarity is observed either between the two habitat types or between the two approaches.

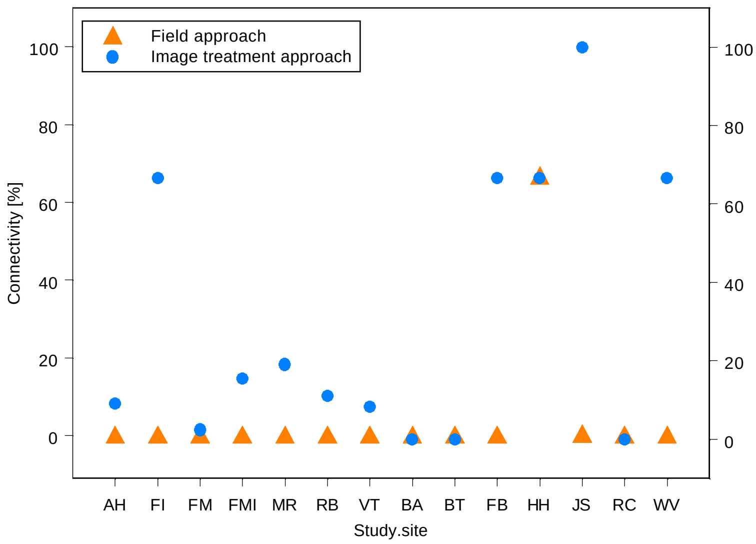


Figure 29: Behavior of the connectivity metric on the class level, for the field approach and the image analysis approach.

In the field approach, most connectivity values are minimal. This translates situations where no patch is connected, hence either the target class consists of one patch solely, or the distance between the patches of the primary forest class is greater than 10 m. The connectivity is maximal when every patch is connected. The target class of study site JS of the image treatment approach is represented by two patches of very different size. One measures over 90% of the whole landscape area and the other some square meters only. Considering the uneven distribution of the primary forest area between the two patches, the situation of JS can be argued to be similar to the ones in landscapes where there is only one patch of primary forest. Because the connectivity index does not consider the size of the patches, this can lead - as this case shows - to important misinterpretations.

Dependency analysis

The question is: “For the metrics on the class level, is there a dependency between the field and the image treatment approaches?”

This is analyzed by using linear and quadratic regression models. The reader is invited to consult appendix 15 for details.

For the patch density metric, the results have shown a significant correlation between the two approaches (p =0.0360), the intensity of the correlation is however week (R^2 = 0.317). The correlation of the shape, ENN and connectivity metrics are insignificant. This means that field and image treatment approach tend to give similar estimations of the patch density, but not of the shape, the ENN and the connectivity. Because of lack of time, we could not analyze the reasons of these results.

A second question is: “For the patch density metric on the class level, is there a difference between the fragmented and the continuous habitat?”

This is analyzed by using the Wilcoxon rank-sum test. The reader is kindly invited to consult appendix 19 for details.

The zero hypothesis of the equal means is discarded (p = 0.0142), hence there is a significant difference between the values of the patch density metrics of the two approaches. The mean patch density in the fragmented habitat (mean = 47) is greater than of the continuous habitat (mean = 15).

Patch level

Area

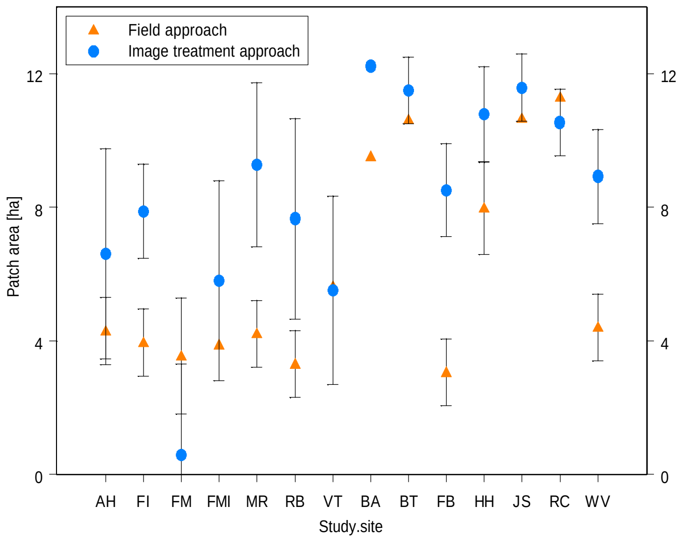


Figure 30: Behavior of the area metric on the patch level, for the field approach and the image analysis approach.

The image approach shows a clear increase in the forest patch area in the more continuous habitat. When excluding site FB and WV from the study, the field approach shows the same dissimilarity for the two habitat types.

The areas of the target patch of the field approach are systematically smaller than the ones of the image analysis approach. The difference is greater in the fragmented habitat than in the continuous. This dissimilarity is due to the inclusion of a greater number of patches in the forest class, which does not occur in the field approach.

The same tendency has been observed for the patch density metric on the class level, earlier in this chapter.

Shape

No dissimilarity is observed between the two habitat types. The mean shape value is higher for the field approach than for the image approach. The same dissimilarity has been observed for the landscape and class level.

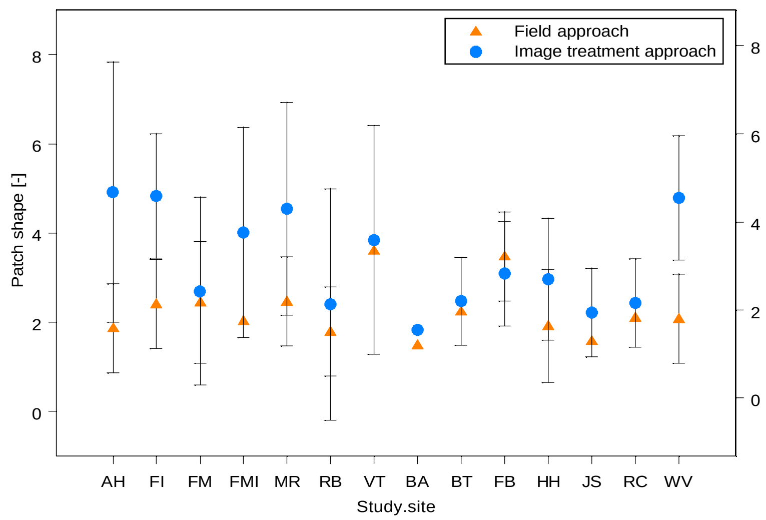


Figure 31: Behavior of the shape metric on the patch level, for the field approach and the image analysis approach.

ENN distance

No dissimilarity is observed either between the two habitat types or between the two approaches.

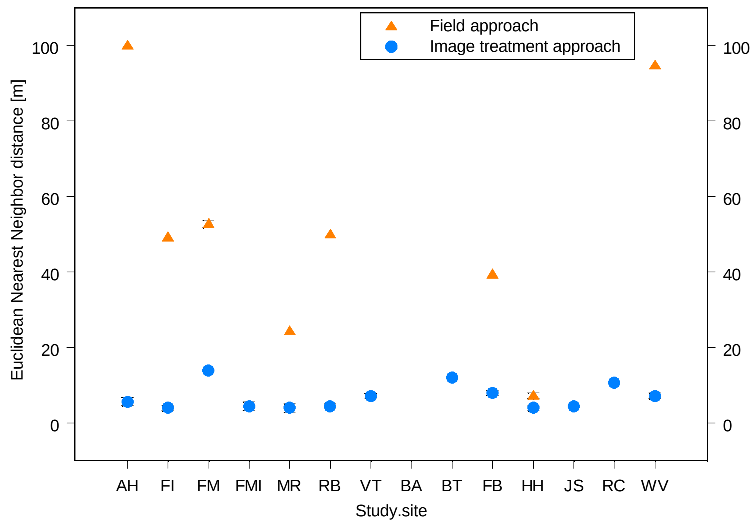


Figure 32: Behavior of the ENN distance metric on the patch level, for the field approach and the image analysis approach.

Dependency analysis

The question is: “For the metrics on the patch level, is there a dependency between the field and the image treatment approaches?”

This is analyzed by using linear and quadratic regression models. The reader is invited to consult appendix 16 for details.

On the patch level, the area metric shows a highly significant, but week correlation between the two approaches (p = 0.0057, R^2 = 0.484). The correlation between the shape and the ENN metrics is insignificant.

5.2.4 Pertinence and limitations of the metrics

Area and patch density are very straightforward metrics and do not risk to be subjects of misinterpretations. However, they are both influenced by the observation scale and hence for a pertinent metric output, the latter one has to be chosen carefully.

Shape and connectivity are more complex metrics and caution should be applied when interpreting them. The shape metric is very sensitive to long narrow objects such as roads. A long road running through a landscape where the shape of the vegetation patches are all close to squares, can lead to an important increase in the shape index. Lies the main interest of the structural analysis in the examination of the level of fragmentation of the vegetation classes, this output might lose signification.

The outputs of the connectivity metric can be disturbed by small pixel aggregations and hence - for the image treatment approach - the choice of an apt filter is necessary in order to obtain a pertinent metric output.

Caution has to be applied when interpreting the ENN distance metric. This metric is an index of the patch distribution and not of the level of fragmentation.

5.2.5 Landscape characterization

The aim of this paragraph is the characterization on the basis of the metric outputs, considering the pertinence of the latter ones.

	Landscape fragm vs cont	Class fragm vs cont	Patch fragm vs cont
Area	/	/	<*
Patch density	>	>*	/
Shape	=	=	=
ENN distance	<	---	---
Connectivity	---	---	/

Table 18: Summary of the differences in the metric outputs between the two habitats, for the field approach and the image treatment approach.

Legend:

/ no computations

--- no differences

* different results for the two approaches (see text)

> smaller values in continuous habitat

< smaller values in fragmented habitat

= same values in both habitats

The area, patch density and ENN distance metrics show different outputs for the two habitat types, whereas shape characteristics seem to hardly vary between the two habitat types. Connectivity is not a metric that allows to characterize the two habitat types.

The area of the target patches of the fragmented habitat is smaller than the ones of the continuous habitat. In the field approach, sites FB and WV disturb this tendency, because their values in the continuous habitat are characteristic of the more fragmented habitat. This problem is not only present at the patch level, but is a reflexion of the general weak forest cover of these two sites.

On the landscape level, the patch density metric translates a higher level of fragmentation for the fragmented habitat than the continuous one. On the class level, this tendency is not present in the field approach. The reason lies in the difference of the classification method (see page 38, figure 26). In the field approach only a well defined vegetation type is included in the target class. As a consequence, the target patch makes out almost the whole area of primary forest which results in a weak patch density.

On all three analysis levels (L, C and P), the shape values do not show differences between the two habitat types. This indicates a similar shape complexity of the image objects in the fragmented and in the continuous habitat. But the decision maker should be reminded of the limitations of this metric (chapter 6.2.3).

On the landscape level, the distances between patches of the same class seem to be smaller in the fragmented habitat than in the continuous. The standard deviations of both approaches are relatively important compared to the mean ENN distances, which translates a relatively irregular patch distribution.

This difference is not present at the class and the patch level, where the characterization of the two habitats is not possible.

In the case the dissimilarities in the metric outputs between the two habitat types, of the two approaches, are important for the study, the following summary of the results can be useful in the choice of the apt metrics.

AREA	The dissimilarity between the two habitat types is present in both approaches.
PATCH DENSITY	The dissimilarities are clearly better displayed by the image analysis approach than by the field approach.
SHAPE	The results of this metric do not display any dissimilarity on the level of the two habitat types.
ENN DISTANCE	The dissimilarity between the values of the two habitat types of the field approach is slightly clearer than the one of the image field approach.
CONNECTIVITY	No dissimilarities are noticed between the two habitat types.

Metric	Dissimilarity Field	Dissimilarity Image treatment
Area	weak	good
Patch density	weak/good	good
Shape	no	no
ENN distance	good	good
Connectivity	no	no

Table 19: Summary of the presence of dissimilarity on the habitat level for the field approach and the image analysis approach.

The shape and connectivity metrics would not be relevant for such a study because of their lack of dissimilarity between the two habitat types. The level of dissimilarity displayed by the area, patch density and ENN distance metrics indicate the image analysis approach to be more apt than the field approach. But the choice favoring one of the two approaches can not be made on these results only.

The patch area of the target patch[16] constitutes an important parameter in the bird species versus landscape structure analysis. The dissimilarity of the area metric of the field method is weak. However, this approach represents the actual field situation. The results of the image analysis approach for this metric are better, but the decision maker has to be aware of the lack of thematic information this approach implies. Is the statistical analysis made on the thematic map of the image analysis approach, the inclusion of patches of small vegetation in the primary forest class may distort study results. Bird species sensitive to changes of vegetation types may actually avoid certain patches classified as primary forest in the landscape model. The ecology of the target bird species is the crucial factor in the decision making process.

16 As target patch is referred to the forest patch where the bird samples are taken.

6 Conclusion

The two habitat types have been differentiated in their state of fragmentation by the metrics of both field and image treatment approach. The patch density is greater in the more fragmented habitat. This tendency can be observed for both approaches on the landscape level and - for the image approach only - on the class level. Latter restriction is due to the classification system of the field approach which excludes certain areas of the primary forest class that are included in the target class of the image treatment approach. The result is an increase in patch density. Furthermore, with the exception of study sites FB and WV of the field approach, the areas of the target patches are bigger in the continuous than in the fragmented area. However, shape complexity of the image objects is similar in both habitat types. Hence, the fragmentation of the forest in Monteverde does not seem to have changed the shape of the fragments. On the landscape level, the distances between patches of the same class are smaller in the fragmented habitat than in the continuous. The important standard deviation of the metric indicates an irregular patch distribution. On the class and patch level, the results do not allow a descriptive statistical discrimination between the two habitat types. The same has been noted for the connectivity metric and hence - for this case study - this metric is not useful for the descriptive structural analysis.

The field approach has shown that the chosen study areas only partly fulfill the hypothesis claiming the forest cover to be 30 to 40% in the fragmented, and at least 60 to 70% in the continuous habitat. Actually, the forest cover of study sites FB and WV in the continuous habitat corresponds more to the required percentage of forest characterizing the fragmented habitat. However, the mean cover of the continuous habitat is at around 70%. For any further proceedings, it has to be decided how these two landscapes will be handled with.

The application of the 7x7 majority filter shows the scale dependency of all chosen metrics. The filter increases the dissimilarities of the area, patch density and ENN distance metric outputs between the two habitat types. In the case of the patch density metric, the filter even has a regrouping effect on the results. Hence, the application of a filter on the thematic map of the image analysis approach has shown clear advantages.

The choice of upper and lower limits of scale, the pixel size and the study area extent, should be chosen to respond to the study aims. The lower limit of scale should correspond to the smallest structural unit that the target species can still percieve as such. The upper limits of scale should include the general habitat extension of the species. The importance of the problem of scale cannot be stressed enough.

The advantage of the field approach lies in its high potential level of thematic detail in the quantitative description of the class distribution in the landscapes. In this study, this has allowed the in part validation of the basic hypothesis of the percentage of forest cover of the two habitats.

The lack of thematic detail in the image analysis approach can lead to misinterpretations of certain metric outputs. But the field approach demands a great temporal and financial investment. The image approach, on the other hand, is a rapid method and applicable on big study areas. Even being characterized by a weak level of thematic detail, the structural detail seems to be better than the one of the field approach. The decision between the field approach and the image analysis approach has to be made on the basis of the ecology of the target species. Is the differentiation between primary forest and secondary forest, agricultural use and seminated, non-native tree species important, the image analysis approach will have certain limitations. On the other hand, is the behavior of the target species not influenced or only influenced in an insignificant way by the differences in these vegetation classes, this approach may constitute a favorable choice.

Because of time restrictions, the comparative analysis of species diversity and individual abundance versus structure metrics had to be discarded. Nevertheless, it constitutes the interesting continuation of this work.

Understanding their limitations, landscape pattern metrics can be used as pertinent tools of landscape ecology for the analysis of landscape structures and the level of fragmentation of a landscape. The comparative analysis of species diversity versus structure metrics can reveal interesting results on the level of the species behavior and species pertinence. Fragmented forests consist of a high number of different habitats and the understanding of their influences on species is difficult. The landscape pattern metrics serve as tools for a better understanding of the influences of landscape structures on species diversity and abundance and for a sustainable management of these areas.

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GLOSSARY

- Abundance. Number of individuals of a certain species.
- Class. Types or groups of ecosystems.
- Ecological corridor. Narrow strip of vegetation, linking two patches.
- Fragmentation. strictly spoken: The separation and drifting apart of formerly continuous habitat into several pieces (fragments).

  in the large sens: Both habitat loss and changes in habitat configuration.
- Geographic Information System GIS: Information system allowing to stock and analyze spatial data and related attributes, consisting of two main components: maps and databases.
- Image classification. Attribution of each image pixel to a thematic class.
- Image rectification. Georeferencing and resampling raw image data.
- Landscape. Heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout.
- Landscape composition. Variety and abundance of a patch type within a landscape, without spatial references such as placement or location of patches.
- Landscape configuration. Physical distribution or spatial character of patches within a landscape.
- Landscape ecology. Study of landscape patterns, the interaction among patches within a landscape mosaic, and how these patterns and interactions change over time. Landscape ecology considers the development and dynamics of spatial heterogeneity and its affects on ecological processes, and the management of spatial heterogeneity.
- Metric. Statistical measure of structural landscape patterns.
- Pixel. Abbreviated from picture element. The smallest part of a picture (image).
- Patch. Habitat fragment considered as a subunit of a patch type (class).
- Richness. Refers to the number of species present in a zone.
- Thematic map. Map consisting of surfaces and land covers attributed to thematic classes.

FIGURES AND TABLES